An Assessment of Anthropogenic Air Pollution Effects to Resources Within the Interior Columbia River Basin

Anna Schoettle
Kathy Tonnessen
John Turk
John Vimont

Ann Acheson
Janice Peterson

AUTHORS

ANNA SCHOETTLE is a plant physiologist at the USDA Rocky Mountain Research Station, Ft. Collins, CO, 80526-2098

KATHY TONNESSEN is an aquatic effects specialist with the USDI National Park Service, Denver, CO, 80225-0287

JOHN TURK is an aquatic effects specialist with the U.S. Geological Survey, Denver, CO, 80225

JOHN VIMONT is a visibility modeler with the USDI National Park Service, Denver CO 80225-0287

EDITORS

ANN ACHESON is the air program manager for Region 1 of the USDA Forest Service, Missoula, MT 59807

JANICE PETERSON is the air quality specialist for the Mt. Baker-Snoqualmie National Forest, Region 6 of the USDA Forest Service, Seattle, WA 98403

Preface

The following report was prepared by University scientists through cooperative agreement, project science staff, or contractors as part of the ongoing efforts of the Interior Columbia Basin Ecosystem Management Project, co-managed by the U.S. Forest Service and the Bureau of Land Management. It was prepared for the express purpose of compiling information, reviewing available literature, researching topics related to ecosystems within the Interior Columbia Basin, or exploring relationships among biophysical and economic/social resources.

This report has been reviewed by agency scientists as part of the ongoing ecosystem project. The report may be cited within the primary products produced by the project or it may have served its purposes by furthering our understanding of complex resource issues within the Basin. This report may become the basis for scientific journal articles or technical reports by the USDA Forest Service or USDI Bureau of Land Management. The attached report has not been through all the steps appropriate to final publishing as either a scientific journal article or a technical report.

ABSTRACT

Schoettle, Anna; Tonnessen, Kathy; Turk, John; and others. 1995. An assessment of anthropogenic air pollution effects to resources within the Interior Columbia River Basin. Gen. Tech. Rep. PNW-GTR-XXX. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 70 p.

An assessment of existing and potential impacts to vegetation, aquatics, and visibility within the Interior Columbia River Basin due to anthropogenic air pollution was conducted as part of the Interior Columbia River Basin Ecosystem Management Project. This assessment used current literature and existing databases to examine the current situation and potential trends due to pollutants such as ammonium, nitrogen oxides, sulfur oxides, particulates, carbon, and ozone. The assessment identifies ecosystems and resources at risk (i.e., certain forests, lichens, cryptogamic crusts, high-elevation lakes and streams, arid lands, and Class I areas), characterizes pollutant levels and exposures needed to cause effects, discusses the significance of emissions not previously considered in emissions inventories, and describes current visibility in Class I areas within the Interior Columbia River Basin and pollution sources which may impact visibility. The assessment also includes a summary of data gaps, and suggestions for future research, development and applications related to air pollution effects and analysis.

Keywords: atmospheric deposition, acid rain, air pollution, aquatic effects, terrestrial effects, sensitive species, visibility.

INTRODUCTION

This chapter evaluates, as part of the ICRBEMP, the current condition and expected trends in air quality and its effects to natural resources within the Interior Columbia River Basin (ICRB). (This chapter is synthesized from the

working document "An Assessment of Anthropogenic Air Pollution Effects to Resources within the Interior Columbia River Basin" (Schoettle and others, in draft)). The focus of the assessment is on the effects of the EPA "criteria" pollutants including particulate matter (PM-10), nitrogen oxides, and sulfur oxides, but also considered volatile organic compounds, ammonium, and ozone as well as some air toxics. This chapter does not include an evaluation of human health effects or an analysis of smoke effects generated from wildland fire.

The evaluation of air quality and its effects within the ICRB was conducted through review of existing data (using national databases when possible) about emissions, atmospheric deposition, snow and lake chemistry, vegetation, and visibility; literature reviews; and conversations with other experts in the field. GIS was used as a mapping tool to identify areas potentially impacted by air pollution based on a resource's sensitivity to air pollution, its proximity to emissions sources, and meteorology. Other politically designated areas sensitive to air pollution, such as Class I or non-attainment areas, were also mapped (fig. 1).

METHODS

Data Used to Evaluate Air Quality Condition

Emissions and monitoring data from within and around the ICRB were used to assess the current and predicted condition of air quality and its effects to resources. The emissions data for point and area sources (excluding silvicultural and agricultural burning) are from 1990 and are the same data compiled for the Grand Canyon Visibility Transport Commission (legislated by Congress to assess visibility and causes of impairment in National Parks and wilderness areas of the Colorado Plateau). These data have been extensively reviewed and validated by the State air regulatory agencies of the affected states.

In general, emissions of air pollutants in the ICRB are lower than in the eastern U.S. or California (EPA 1994) so ICRB air quality can be assumed to be relatively cleaner; however, long-term air quality monitoring data for the ICRB does not exist (Lefohn and Lucier 1991, Böhm 1992).

Ambient air monitoring data from national, state or local monitoring were obtained either through the national EPA emissions inventory database or from the individual state agencies. The most recent year of data was used which was either 1991, 1992 or 1993. Specifics on other monitoring data used in this report are described later in the text.

RESULTS AND DISCUSSION

The need for abundant and reliable new energy sources, minerals, timber, and agricultural production may result in increased atmospheric emissions of pollutants in the ICRB and other western areas. To wisely use these resources without damaging nearby wilderness areas and other federal lands, land management decisions need to be based on an understanding of the present status of the ICRB's resources and the potential risk associated with atmospheric emissions.

Air Pollutants of Concern

Sulfur oxides (SO_x)--This gaseous pollutant, along with secondary pollutants such as sulfuric acid and sulfate particles can affect vegetation, certain lakes and streams, and visibility. Anthropogenic sulfur probably enters the ICRB from the large area and point sources located outside of and within the assessment boundary. The largest point sources, emitting more than 5,000 tons of sulfur per year, are located in the counties of Spokane WA, Morrow OR, Humboldt NV, Bannock ID, Caribou ID, Lewis and Clark MT, and Sublette WY (fig. 2). Area sources are aggregated by county. The counties within the ICRB

having SO_x emissions between 1,000 and 5,000 tons per year are associated with the cities of Boise, Lewiston, and Idaho Falls, ID; Spokane, WA; and Bend, OR (fig. 3).

Nitrogen oxides (NO_x)--This gaseous pollutant, along with secondary pollutants such as nitrates, nitric acid, and ozone can affect N cycling, surface waters acidification and health of vegetation. Area sources for NO_x are more dispersed than for SO_x, but still associated with urban areas both within the ICRB and on its western edge (fig. 4). The areas with the largest NO_x emission inventory are in the Portland, OR and Seattle-Tacoma, WA areas, with emissions exceeding 20,000 tons per year. It is likely that the majority of these emissions are from vehicles.

Ozone (O_3)--Ozone is a colorless, odorless gas that is a secondary pollutant produced when emissions of volatile organic compounds (VOCs) combine with NO_x emissions in the presence of sunlight. Ozone is highly phytotoxic to plants and is likely to affect vegetation in the ICRB because it is found globally in elevated concentrations and because ozone precursors, e.g., NO_x is increasing within and upwind of the ICRB. However, our assessment of ozone effects on vegetation is limited both by inadequate monitoring data (Böhm 1992, Böhm and others 1995) and uncertainties in area emission estimates of NO_x within the ICRB. Ozone does not affect aquatic resources. High concentrations of ozone have been measured near The Dalles, Oregon (1 hour maximum, 92 ppb)(WA, DEQ personal communication). Ozone concentrations are also elevated in the Spokane, WA area (Böhm and others 1995) and are likely elevated in other ICRB urban areas (Boise, ID and the TriCities, WA).

Particles--Small particles may originate from road dust, agricultural and silvicultural burning, volcanic eruptions, or result from atmospheric transformation of NO_x and SO_x to form ammonium nitrate and ammonium sulfate particles. Small particles (0.1 to 1.0 micron category) can reduce visibility

to the point of obscuring views (Malm 1992). Nitrate and sulfate particles can also add to total loadings to forests and surface waters, resulting in acidification, eutrophication, and nitrogen saturation. Small particles can negatively affect human lung function.

Other pollutants of concern in the ICRB, for which there is little information, include radionuclides, mercury and other metals, and persistent organic pollutants.

Deposition of Air Pollutants

Wet and dry deposition--Wet deposition includes rain, snow, sleet and hail, along with "occult" deposition (fog and cloud water). Dry deposition includes chemicals deposited as particles and gases. Chemical species of interest in determining the dose to the ecosystem include sulfate (SO_4), nitrate (NO_3), ammonium (NH_4), and hydrogen ion (pH). There are nine National Atmosheric Deposition Program (NADP) wet deposition monitoring sites in the ICRB (fig. 5). The precipitation-weighted pH of wetfall measured at these nine sites ranges from 5.3 at Glacier National Park to 6.0 at Reynolds Creek. Dry deposition is measured within the ICRB at three sites: Reynolds Creek, ID; Glacier National Park, MT; and Saval Ranch, NV. The 1990 data show that nitric acid has the highest loading of all the dry species at all three sites, with a range of 1 kg ha^{-1} at the Glacier National Park site to about 2.5 kg ha^{-1} at the two more southerly sites.

Cloud water and fogwater monitoring--Böhm (1992) summarized what is known about the contribution of cloud water to high-elevation areas in the vicinity of the ICRB including the Washington Cascade Range and Mt. Werner in the Rocky Mountains of northwest Colorado. Cloud water pH's ranged from 3.1 to 5.9 in the Washington Cascade Range and from 3.0 to 5.2 at Mt. Werner, Colorado.

Snowpack monitoring--Regional snow deposition is sampled along the Continental Divide in Montana, Wyoming, Colorado, and New Mexico, carried out by the U.S. Geological Survey, in cooperation with the USDA-Forest Service, National Biological Service, State of Colorado, and National Park Service (Turk, 1995). An earlier synoptic snow monitoring project along the Cascade Range and Sierra Nevada crest is reported in Laird and others (1986).

Snowpacks in the ICRB tend to have dilute chemistry (figs.6, 7, 8). During the Laird and others (1986) survey of February through March 1983, the pH's of the snowpack along the Washington, Oregon, and northern California Cascade Range ranged from 5.11 to 5.88, with nitrate concentrations in the range of 0.007 to 0.12 mg L^{-1} and sulfate from 0.05 to 0.32 mg L^{-1} . The pH's of snowpack recorded in the Rocky Mountains during 1993 were mostly above 5.0, with the exception of sites in the vicinity of the Mt. Zirkel Wilderness Area, where researchers have suggested that emissions from local sources in the Yampa Valley are influencing snow chemistry.

Predicting Response of Aquatic Ecosystems to Air Pollutants

Aquatic ecosystems include the obvious hydrologic components of lakes, streams, and ground water and the rain, snow, and fog that replenish them. Other critical components include bedrock and surficial materials, soils, and terrestrial and aquatic communities that define much of their character, and the movement of water, nutrients, and toxic materials through the ecosystem. Unfortunately, consideration of the many possible complex interactions of all these components with air pollutants would be difficult at best in intensively studied watersheds and impossible in the many remote wilderness areas and other federal lands in the ICRB. This section presents a regionally oriented approach to help the reader determine the present status of aquatic resources, and assess the risk of future threats to aquatic resources from air pollutants, in the ICRB. Most of this discussion uses existing data on lakes,

snowpack, and rain plus snow (wetfall). These hydrologic components integrate many of the complex interactions of their respective ecosystems and allow the reader to rank the degree of threat and sensitivity to that threat.

One useful approach to predicting response of aquatic ecosystems to air pollutants is to consider:

1. Present status of aquatic ecosystems with respect to critical levels of some measure of ecosystem health, for example, pH.

2. Ability of aquatic ecosystems to respond to additional threats to ecosystem health, for example, acid neutralizing capacity (ANC).

3. Present geographic distribution of air pollutant concentrations.

4. Location of aquatic ecosystems already affected by air pollutants or having very little ability to respond to increased air pollutants in the future.

Aquatic resources at low elevation tend to be less sensitive to acid rain than high elevation lakes and streams, however, lakes at any elevation could be sensitive to other atmospheric pollutants due to the same chemical and biological processes and characteristics that determine sensitivity to acid rain. For example, low pH and small ANC would tend to make a lake sensitive to many toxic metals whose solubility is increased at low pH. Further, the short hydrologic flowpaths and thin soils typical of lakes sensitive to acid rain provide minimal opportunity to remove inorganic and organic air pollutants by sorption to soil or by biological uptake or degradation. Thus, knowledge gained from acid rain studies can be used to select aquatic resources that may be sensitive to other air pollutants.

Sources of historical data and background information include:

Lake information--Most knowledge of the present status of aquatic resources of the ICRB and risk from air pollutants has been summarized by Turk and Spahr (1991), Nelson (1991), and Melack and Stoddard (1991). These references discuss the 1985 EPA Western Lake Survey - the only lake study which included the entire ICRB - and numerous smaller studies.

Atmospheric deposition information--The National Atmospheric Deposition Program was discussed earlier in this paper as was snowpack data.

Watershed processes information--A collaborative effort between six federal agencies recently resulted in published results from the 10-year National Acid Precipitation Assessment Program (NAPAP 1991). Although the NAPAP focus was primarily on the eastern U.S., much of what we know about the effects of air pollution on aquatic ecosystems is a result of NAPAP and related work.

Present status of aquatic ecosystems--The only geographically extensive historical data are for lakes rather than streams (fig. 9). In the ICRB, most lakes have pH between 6 and 8 and only two have pH less than 6. The pH data typically represent conditions during summer and fall although lower pH is expected to occur during snowmelt, for which data are unavailable. Mortality in amphibians common to lakes and ephemeral pools in alpine areas occurs at pH values as high as 5 to 6 (Harte and Hoffman 1989, Corn and Vertucci 1992). Thus, pH of lakes typically is not at a critical level for the ICRB during the summer and fall sample period.

Seasonal snowmelt supplies most of the water in sensitive lakes, ephemeral breeding pools, and low order streams, all of which tend to occur in alpine and subalpine areas of the ICRB. At times, this snowmelt may totally or largely displace more alkaline water that typically would occupy such systems

during periods other than snowmelt. Thus, surveys conducted during summer and fall, the case for all lake surveys referenced above, may provide a poor estimate of worst-case acidification of aquatic systems. The chemical nature of this snowmelt, and aquatic systems most influenced by it, may be a more appropriate measure of aquatic chemistry than is the chemistry of lakes reported by the surveys above. It is possible that areas having lakes with insufficient ANC to buffer acidity released during snowmelt may experience episodic pH low enough to result in biological damage, but data are not available to determine whether this occurs in the ICRB.

Ability of aquatic ecosystems to respond to additional threats--Lakes are ranked in sensitivity to acidification based on their acid neutralizing capacity (ANC). To be able to buffer atmospheric deposition as acidic as is commonly observed in the eastern U.S., and to retain a moderate amount of ANC to provide stability in pH, an ANC of 200 micro equivalents per liter ($\mu eq\ L^{-1}$) is often used to divide sensitive (ANC < 200 $\mu eq\ L^{-1}$) and non-sensitive (ANC > 200 $\mu eq\ L^{-1}$) lakes (Hendrey and others 1980). Many lakes in the ICRB have ANC less than 200 $\mu eq\ L^{-1}$ and numerous clusters of lakes have ANC much less than 200 $\mu eq\ L^{-1}$ (fig. 10). However, no acidic (ANC < 0) lakes have been identified in the ICRB.

Geographical distribution of air pollutant concentrations--Air pollutants can directly enter aquatic ecosystems as solutes in wetfall and from the snowpack. The present geographic distribution of areas of greater concentration of air pollutants in snowpack can be seen for pH (fig. 6), nitrate, (fig. 7) and sulfate (fig. 8). Generally, the smallest concentrations of air pollutants in the snowpack are in the Cascade mountains, the Sierra Nevada mountains, and in Montana. Concentrations are greatest in Wyoming and in a small area within Montana near the junction with Idaho and Wyoming. Some of the largest concentrations of sulfate, nitrate, and acidity were measured at sites in this area west of Yellowstone National Park.

Generally wetfall sites near snowpack sampling sites shown in figures 6, 7, and 8 have values comparable to the snowpack values. Wetfall sites at lower elevation, however, have somewhat greater concentrations than do the snowpack sites. Much of this difference is caused by a seasonal pattern with greatest concentration of air pollutants in the summer and smallest concentration in the winter, when the snowpack accumulates.

Location of aquatic ecosystems affected by or sensitive to air pollutants--

Because of differences in bedrock geology, soil development, and hydrology, those Rocky Mountain lakes having smallest ANC are clustered in specific mountain ranges such as the Bitterroot Range (Montana) and the Wind River Range (Wyoming). Lakes in the Cascade Range and the Sierra Nevada with small ANC tend to be more evenly distributed. Many of these clusters of low ANC lakes occur within class I areas (fig. 10). The greatest risk of damage from atmospheric deposition is likely in these clusters of lakes with very low ANC and nearby, but unsampled, lakes, streams, and ephemeral pools.

Routine chemical analyses of the snowpack and wetfall as well as of the lakes, streams, ponds, and ephemeral pools would be most effective in protecting critical aquatic ecosystems if focused on low ANC systems.

Information needed for assessing future risks to aquatic ecosystems--Lakes and streams in the ICRB indicate little evidence of acidification; however, many are likely to respond rapidly to changes in atmospheric deposition. Considering the number of lakes and streams in the region, and the number of important watershed characteristics that may affect watershed response to acidity, few index systems are monitored routinely. Thus, preparation of any watershed model appropriate for the evaluation of regional acidification is hampered. Such models need to be calibrated as a function of the variability of geology, soil, vegetation, climate, atmospheric deposition, and hydrologic

characteristics common to the region. Presently (1995), data do not exist to calibrate and verify such models, except for a few individual watersheds.

At present, monitoring networks have few sites at appropriate elevations to determine adequately whether watersheds are adversely affected by atmospheric deposition. Instruments that work at high elevations are difficult to use or unreliable, so data on the quantity and quality of wetfall at high elevations generally are unavailable. Further, direct measurements of dry deposition, fog, and rime ice, are needed at high elevations.

Because of access problems at high elevations, measurements of aquatic chemistry during periods of snowmelt or intense rainfall are hindered. Most data collections of lake and stream chemistry are restricted to sampling during midsummer through early fall. This period is not as likely to indicate early stages of acidification as is the period of snowmelt.

Only a few watersheds in the Rocky Mountain region have been studied with respect to watershed processes that are important to acidification. Regional data about soil-exchange chemistry, weathering reactions, ground-water chemistry, in-lake processes, and hydrologic flow paths are almost nonexistent. These same data are even less common in watersheds typical of those sensitive to acidification. No catchment-size areas exist in sensitive watersheds in which experimental manipulation has been done.

To evaluate or predict acidification of sensitive watersheds it will be necessary to determine how much effect a given change in emissions from a particular source(s) will have on atmospheric deposition. The comparative affects of local, regional, or extra-regional anthropogenic or natural sources in controlling the chemistry of atmospheric deposition needs to be determined.

In summary, watershed studies need to represent the variety of geographic,

geologic, and the full seasonal range of hydrologic conditions common to watersheds sensitive to acidification. Better information is needed on the effects of changes in emissions to atmospheric deposition and how those changes affect watersheds. Watershed and in-lake processes need to be incorporated into realistic models to simulate existing conditions and response to pollution sources, to predict effects from potential sources, and to guide data collection and monitoring.

Predicting Response of Terrestrial Ecosystems to Air Pollutants

To assess present impacts of air pollutants on vegetation in the ICRB, we have chosen to concentrate on four major air pollutants: sulfur dioxide (SO_2), nitrous oxides (NO_x), ozone (O_3), and fluoride (F). Less emphasis is placed on F since it is now only locally important. Ozone will increase with increases in NO_x emissions. Thus, its potential effects on vegetation in the ICRB are emphasized.

Sulfur dioxide--Ambient SO_2 within the ICRB is contributed by sources within the area as well as transported from sources outside of the area. To protect vascular plants and lichens from direct damage caused by sulfur dioxide, annual mean SO_2 should not exceed 8 to 12 ppb and 3 to 5 ppb, respectively. Within the ICRB there are only three SO_2 monitoring stations. They all report mean annual concentrations of SO_2 below the suggested thresholds to protect vegetation. It is not possible to say conclusively that SO_2 is not a threat to vegetation within the assessment area without additional ambient air monitoring and field surveys of vegetation and lichens.

Nitrogen oxides--Area source estimations of NO_x emissions are not accurate. NO_x emissions from fertilized agricultural land may be substantial in the ICRB, yet are not accounted for in the NO_x inventory. Vegetation can be impacted directly by increased inputs of N via wet or dry deposition or

indirectly through fertilization effects and NO_x mediated increases in ozone. For direct impacts to occur, concentration of 0.1 ppm NO_x for over 100 days of exposure are likely to be needed to affect plant metabolism and growth. It is unlikely that this level of sustained exposure is occurring within ICRB. The highest potential for vegetation to be affected by NO_x in the ICRB is via indirect effects of N deposition on species composition within unmanaged, N-limited ecosystems. NO_x emissions will have a significant affect on O_3 formation within the ICRB which may affect plant growth.

Ozone--O_3 and its precursors can be transported hundreds of miles, and can therefore threaten resources in remote areas. Ozone has the greatest potential of any air pollutant to directly reduce growth and vigor of vegetation in the ICRB because it is highly phytotoxic and is found globally in elevated concentrations. In addition, the level of its precursors (NO_x and hydrocarbons) is increasing within and upwind of the ICRB. Ambient air quality data for O_3 in the ICRB is less well characterized than for the rest of the U.S. The most sensitive tested species within the ICRB may be impacted by a 7 hour growing-season mean of 60 to 90 ppb O_3 for conifers and 70 to 120 ppb O_3 for hardwoods. Recent analyses of O_3 monitoring data in the western U.S. suggest that the seasonal mean O_3 concentrations are significantly below these suggested threshold levels. However, these levels may be exceeded near urban areas or downwind from sources of O_3 precursors. Ozone-induced stress can also have secondary effects beyond reduced growth, such as increased susceptibility to root rot and insect infestation.

Fluoride--The advent and implementation of new technologies for control of F emissions within the aluminum industry has greatly reduced F emissions within the ICRB. Current impacts due to F are likely to be limited to proximity to the few point sources within the ICRB.

Predicting Response of Visibility to Air Pollutants

Visibility is an important air resource. Congress recognized this and included visibility protection as part of the 1977 Clean Air Act amendments. In section 169A, Congress declared, as a national goal, "the prevention of any future, and the remedying of any existing, impairment of visibility in mandatory class I Federal areas which impairment results from manmade air pollution."

The available data for characterizing visibility conditions in the ICRB come from the IMPROVE (Interagency Monitoring of Protected Visual Environments) monitoring network. IMPROVE sites generally include aerosol and optical measurements. The aerosol sampling is accomplished by a combination of particle collection and sample analysis. View monitoring is also performed. Three color slides are taken each day, via automatic camera, to document the appearance of a selected scene.

The IMPROVE monitoring stations within the ICRB area are all near the perimeter of the area. These sites are the Columbia River Gorge Scenic Area (CORI), Snoqualmie Pass (SNPA), Crater Lake National Park (CRLA), Lassen Volcanic National Park (LAVO), Jarbidge Wilderness Area (JARB), Yellowstone National Park (YELL), and Glacier National Park (GLAC). There is also an IMPROVE site at Mount Rainier National Park (MORA), which is just outside of the ICRB boundary; the actual monitoring site is located at low elevation on the west side of the park. The interior of the ICRB is not well characterized; conditions in the interior may be different from what is measured on the periphery.

Visibility at the sites is quite variable as seen in figure 11, where visibility is expressed in terms of standard visual range (SVR). The more northerly sites, CORI, GLAC, MORA, and SNPA all have much lower average visual

ranges than the more southerly sites. The southerly sites all have average standard visual ranges in excess of 130 kilometers, while all of the northerly sites are less than 80 kilometers. The JARB site exhibits some of the best visibility conditions of any of the sites in the IMPROVE network, with an annual average standard visual range of 168 kilometers.

One of the differences of the three sites along the northern Cascade Range (SNPA, MORA, and CORI), relative to the other sites in the region, are their proximity to the upwind pollution source areas of western Washington and Portland, Oregon. This leads to elevated sulfate and, at CORI and SNPA, nitrate concentrations. MORA is located slightly west of Mount Rainier National Park and at relatively low elevation. MORA is likely to be more affected by sources in the Puget Sound region and the Western Washington lowlands than sites actually located in the ICRB. While SNPA and CORI are both within the ICRB area, they are each located near the boundary and are at low points in the Cascade Range where pollutants are channeled from the urban areas of Seattle and Portland. Major interstate highway routes run over Snoqualmie Pass and along the Columbia River as well. The CORI site may also be affected by various industrial facilities located along the Columbia River.

While there are elevated nitrate concentrations at CORI and SNPA, the nitrate aerosol may not be transported very far into the interior of the ICRB region. Ammonium nitrate aerosol is in equilibrium with its gas phase components and can revert back to those components. Generally, cool, moist conditions are more favorable for the formation of ammonium nitrate aerosol, while warmer dryer conditions are more favorable for the gaseous components. Therefore, ammonium nitrate can be somewhat transient in the atmosphere and is usually not measured in high concentrations at sites distant from source areas.

At all of the sites in and around the ICRB, carbon, in its various forms

dominates the extinction budget. Figure 12 displays the same information as Figure 13, but combines the organics and soot categories into "total carbon." With the exception of the sites along the northern portion of the Cascade Range, total carbon accounts for more than 50% of the total aerosol extinction. This has certain implications for forest management practices in the ICRB. Carbonaceous aerosols are emitted by forest burning. Dramatic increases in burning are likely to degrade visibility in the protected areas of the region. Burning practices will have to be considered for improvements to be made in visibility conditions.

The data discussed here has been presented as annual average conditions for comparison between sites. Depending on the use of the data, other statistical groupings may be more appropriate. For example, the distribution of aerosols on the worst visibility days would be worth examining if the management objective was to try to remedy some existing visibility impairment on those days. Conversely, the relative distribution of aerosols on the best visibility days would be more appropriate if the management objective is the protection of the cleanest days. Similarly, the visibility conditions also vary by season. If management options being examined are seasonal in nature, seasonal visibility values should be determined.

SUMMARY

Ecosystems and Resources at Risk from Air Pollution Within the ICRB

Forests--Ponderosa pine within the ICRB is likely to be especially sensitive to ozone and is at high risk of injury if ozone levels continue to rise. The forests are also at risk for alteration of growth rates and patterns, soil acidification, shifts in species composition, and modification of the effect of natural stresses such as drought and insect infestation in response to N and S deposition. One of the biggest unknowns relative to the effects of air

pollution on these forests is the status of forest soils and the effects of nitrogen deposition on nutrient cycling, particularly in forest stands disturbed by fire, pests, and disease outbreaks.

High-elevation lakes and streams--Sensitive aquatic resources include low-ANC lakes found in the Cascade Range (WA, OR, CA), the Idaho Batholith (ID, MT), mountain ranges of northwestern Wyoming, and Rocky Mountains in Colorado (EPA 1995). Low-ANC lakes and streams at high elevations are susceptible to episodic acidification associated with intense rains or spring snowmelt. EPA's Western Lake Survey detected measurable amounts of nitrate in lakes found in northwestern Wyoming and the Colorado Rocky Mountains.

Arid lands--Areas of eastern Oregon and Washington and southern-central Idaho may be considered part of the Great Basin and Intermountain desert and semi-desert ecoregions, where little research or monitoring has been done to determine levels of air pollutants and their effects. These regions depend on the integrity of crypotogamic crusts for soil stabilization; the effects of acid and nitrogen inputs to these biological systems are not known.

Class I areas--Class I wilderness areas and parks (fig. 1) have air quality related values, e.g., vegetation, water, soil, fauna, and ecosystem processes, that must be protected from air pollutant injury. High elevation vegetation may be particularly at risk from ozone since ozone concentrations are often highest at these elevations. High elevation lakes, streams and watersheds found in wilderness areas and parks are most susceptible to acidification and nitrogen saturation.

RESEARCH, DEVELOPMENT, AND ASSESSMENT

Future air quality assessments should include:

1. Integration of criteria air pollutants and deposition information with information on other pollutants of interest (for example organics and particles from wildfires, pesticides and herbicide transport, and toxic air contaminants identified in the Clean Air Act Amendments of 1990).

2. Continued and augmented monitoring of pollutants important to ecosystem function in the ICRB including (1) high elevation monitoring of rain and snow with emphasis on quantification of nitrogen species, (2) dry deposition monitoring, (3) ozone monitoring in remote areas using both continuous and integrated methods, (4) preliminary assessment of levels of persistent organic pollutants.

3. Creation of an AQRV inventory for each of the class I areas and other sensitive ecosystems and watersheds within the ICRB. Once this inventory is compiled, federal and state agency personnel should devise an AQRV monitoring program to detect changes in response variables in the sensitive ecosystems. Before this monitoring program is implemented, it will be necessary to sponsor dose-response experiments to determine levels of pollutants that might affect sensitive endpoints (for example fumigation experiments on representative vascular plant species; acidification and nitrogen addition experiments to determine degree of change in surface water chemistry and biota).

4. Discussion of population growth, planned development activities and the projection of future emissions, transport, transformation, and deposition and the effects of these increases in emissions on human health, and resource degradation. Special attention should be paid to ecosystem level effects and impact on AQRVs in wilderness areas and national parks.

5. Ecosystem level assessment. Extensive information about sensitive processes and populations found in the ICRB at risk from air pollutants and deposition is needed. These include forests, high-elevation lakes and

streams, arid lands, and wilderness ecosystems. A more thorough assessment of the potential impacts of air pollutants and deposition on ecological and biological resources, for example aquatic biota, watershed processes, and nutrient cycling is needed. This can only be accomplished with the collection of ecosystem-wide data on current status and the prediction of future condition under different air quality scenarios. This type of prediction will be furthered through the use of models and experimental manipulations in the field. This level of research and monitoring will require a commitment of funds and the cooperation and coordination among agencies with interest in air quality and ecosystem integrity.

6. More information related to vegetation - air quality relationships within the ICRB are needed. Additional air quality monitoring within the ICRB is needed, especially in environments similar to, and near Class I areas and high elevation ecosystems. To assess the impacts of sulfur deposition, surveys to identify the lichen and other cryptogamic species within the ICRB are needed coupled with controlled dose-response studies to estimate sensitivities and the likelihood of current impacts to biodiversity and function. Additional information is also needed on the sensitivity of cryptogamic crust establishment to SO_2 exposure, in both disturbed (grazed) and undisturbed areas, due to its importance for soil stabilization and nitrogen cycling.

Regarding NO_x, future assessments will require improved accuracy of NO_x emission estimates including non-urban and area NO_x sources; increased understanding of nitrogen cycling in ICRB ecosystems; and estimates of impacts of sustained low-level N deposition on productivity and nutrient cycling.

Increased monitoring of ambient ozone in areas with potential for ozone formation are needed. This is especially needed for high elevation remote locations that may be downwind from potential sources of precursors. Improved pollution modeling capacities to more accurately predict ambient air quality

of the ICRB (including improved area source estimates of NO_x) would greatly improve our ability to assess vegetation condition. A methodology and model to predict plant sensitivity to ambient ozone exposure is needed for native species. For specific species of interest in area with potential for ozone formation, controlled dose response studies to identify visual symptomology are needed in combination with field surveys to determine if current ozone concentrations are producing visible symptoms.

Literature Citations

Böhm, Margi. 1992. Air quality and deposition. In: Olson, R.; Binkley, D.; Bohm, M., eds. The Response of Western forests to Air Pollution. New York: Springer-Verlag: 63-152.

Böhm, M.; McCune, B.; Vandetta, T. 1995. Ozone regimes in or near forests of the western United States: I. regional patterns. Journal Air & Waste Management Association. 45: 235-246.

Corn, P.S.; Vertucci, F.A.; 1992. Descriptive risk assessment of the effects of acidic deposition on Rocky Mountain amphibians: Journal of Herpetology. 26:361-369.

Environmental Protection Agency. 1994. National Air Pollutant Emission Trends, 1900-1993. EPA-454/R-94-027. Research Triangle Park, NC, Office of Air Quality Planning and Standards.

Environmental Protection Agency. 1995. Acid deposition standard feasibility study: draft report to Congress. U.S.Environmental Protection Agency report; contract EPA 430-R-95-001. 105 p.

Harte, J.; Hoffman, E. 1989. Possible effects of acidic deposition on a Rocky Mountain population of the tiger salamander *Ambystoma tigrinum*: Conservation Biology. 3: 149-158.

Hendrey, G.R.; Galloway, J.N.; Norton, S.A.; and others 1980. Geological and hydrochemical sensitivity of the eastern United States to acid precipitation. EPA/600/3-80/024. U.S.Environmental Protection Agency, Corvallis, OR.

Laird, L.; Taylor, H.; Kennedy, V. 1986. Snow chemistry of the Cascade-Sierra Nevada Mountains. Environmental Science Tech. 20: 275-290.

Lefohn, Allen S.; Lucier, Alan A. 1991. Spatial and temporal variability of ozone in forested areas of the United States and Canada: 1978-1988. Journal Air and Waste Management Association. 41(5): 694-701.

Malm, W. 1992. Characteristics and origins of haze in the continental United States. Earth-Science Reviews. 33: 1-36.

Melack, J.M.; Stoddard, J.L. 1991. Sierra Nevada. Springer-Verlag, New York, N.Y. 747 p.

Nelson, P.O. 1991. Cascade mountains. In: Charles, D.F., ed. Acidic deposition and aquatic ecosystems: regional case studies. New York: Springer-Verlag.

Turk, J. 1995. Effects of energy resource development on lakes - what do we need to know? In: Carter, L.M.H. Energy and the environment - application of geosciences to decision-making. Tenth V.E. McKelvey forum on mineral and energy resources, U.S. Department of Interior, Geological Survey - Circular 1108. Washington, D.C.

Turk, J.; Spahr, N. 1991. Rocky Mountains. In: Charles, D., ed. Acidic deposition and aquatic ecosystems: regional case studies. New York: Springer-Verlag.

Schoettle, A.; Tonnessen, K.; Turk, J.; and others (draft) Acheson, A.; Peterson, J. eds. An asessment of anthropogenic air pollution effects to resources within the interior Columbia River Basin. In: Keane, R.E. and others, eds. Broadscale landscape dynamics of the Interior Columbia Basin. Gen. Tech. Rep. PNW-xxx Portland, OR U.S. Department of Agriculture, Forest

Service, Pacific Northwest Research Station.

Washington Department of Agriculture, Pesticide Management Division. 1994. July 01, 1992-June 30, 1993 annual tonnage reports commercial fertilizers including limes. Olympia, WA.

FIGURE CAPTIONS

Figure 1--Class I and non-attainment areas within or near the Interior Columbia River Basin. See Appendices 1 and 2 for specific information regarding Class I and non-attainment areas.
(air_class_nonatt_bw8x11.aml)

Figure 2--Sulfur oxide(SOx) point source emissions within or around the Interior Columbia River Basin.
(airp_point_sox_new_11x8.5.aml)

Figure 3---Sulfur oxide(SOx) area source emissions within or around the Interior Columbia River Basin.
(airp_area_sox_new_11x8.5.aml)

Figure 4--Nitrogen oxide (NOx) area source emissions within or around the Interior Columbia River Basin.
(airp_area_nox_new_11x8.5.aml)

Figure 5--1992 National Atmospheric Deposition Program (NADP) monitoring sites.
(arm_nadp_location_bw8x11.aml)

Figure 6--Snowpack pH values from sampling sites within or near the Interior Columbia River Basin (from Turk 1995; Laird and others 1986)
(airm_snowpack_bw8x11.aml)

Figure 7--Nitrate (NO_3) values from snow sampling sites within or near the Interior Columbia River Basin (from Turk 1995; Laird and others 1986)
(airm_snowpack_bw8x11.aml)

Figure 8--Sulfate(SO_4) values from snow sampling sites within or near the Interior Columbia River Basin (from Turk 1995; Laird and others 1986) (airm_snowpack_bw8x11.aml)

Figure 9--Lake pH values from sites within or near the Interior Columbia River Basin (from Eilers 1987).
(airm_lakeph_11x8.5.aml)

Figure 10--Lake acid neutralizing capacity (ANC)values from sites within or near the Interior Columbia River Basin (from Eilers 1987).
(airm_lakeANC_11x8.5.aml)

Figure 11--Standard Visual Range, expressed as an annual average, in kilometers, for the Eastside IMPROVE sites. [Columbia River Gorge Scenic Area (CORI), Snoqualmie Pass (SNPA), Crater Lake National Park (CRLA), Lassen Volcanic National Park (LAVO), Jarbidge Wilderness Area (JARB), Yellowstone National Park (YELL), and Glacier National Park (GLAC), Mount Rainier National Park (MORA)]

Figure 12--Aerosol extinction budget with organics and soot combined into total carbon. (*The period of record for CORI and SNPA is from 6/93 to 8/94). [Columbia River Gorge Scenic Area (CORI), Snoqualmie Pass (SNPA), Crater Lake National Park (CRLA), Lassen Volcanic National Park (LAVO), Jarbidge Wilderness Area (JARB), Yellowstone National Park (YELL), and Glacier National Park (GLAC), Mount Rainier National Park (MORA)].

Figure 13--Percentage of light extinction due to aerosol components. (*The period of record for CORI and SNPA is from 6/93 to 8/94). [Columbia River Gorge Scenic Area (CORI), Snoqualmie Pass (SNPA), Crater Lake National Park (CRLA), Lassen Volcanic National Park (LAVO), Jarbidge Wilderness Area (JARB), Yellowstone National Park (YELL), and Glacier National Park (GLAC), Mount

Rainier National Park (MORA)].

APPENDIX 1

Class I areas within the Eastside Ecosystem Management Project (from 40 CFR 81.400, revised July 1, 1994).

CLASS I AREA	STATE	MANAGING AGENCY	ACREAGE
Caribou Wildern.	California	USDA FS	19,080
Lava Beds Wildern.	California	USDI NPS	28,640
South Warner Wildern.	California	USDA FS	68,507
Thousand Lakes Wilder.	California	USDA FS	15,695
Marble Mtn Wildern.	California	USDA FS	213,743
Lassen Volcanic N.P.	California	USDI NPS	105,800
Hell's Canyon Wildern.[1]	Idaho	USDA FS	83,800
Sawtooth Wildern.	Idaho	USDA FS	216,383
Selway-Bitterroot Wild.[2]	Idaho	USDA FS	988,770
Crater of the Moon Wildern.	Idaho	USDI NPS	43,243
Yellowstone N.P.[3]	Idaho	USDI NPS	31,488
Flathead Reservation	Montana	Tribal	
Anaconda Pintler Wildern.	Montana	USDA FS	157,803
Bob Marshall Wildern.	Montana	USDA FS	950,000
Cabinet Mountains Wildern.	Montana	USDA FS	94,272
Gates of the Mountains Wildern.	Montana	USDA FS	28,562
Scapegoat Wilderness	Montana	USDA FS	239,295
Selway-Bitterroot Wilderness	Montana	USDA FS	251,930
Yellowstone N.P.Park	Montana	USDI NPS	167,624

[1] Hell's Canyon Wilderness, 192,700 acres overall, of which 108,900 acres are in Oregon and 83,800 acres are in Idaho.

[2] Selway-Bitterroot Wilderness, 1,204,700 acres overall, of which 988,700 acres are in Idaho and 251,930 are in Montana.

[3] Yellowstone National Park, 2,219,737 acres overall, of which 2,020,625 acres are in Wyoming, 167,624 acres are in Montana, and 31,488 are in Idaho.

APPENDIX 1 (con't)

CLASS I AREA	STATE	MANAGING AGENCY	ACREAGE
Glacier N.P.	Montana	USDI NPS	1,012,599
Red Rock Lake Wildife Refuge	Montana	USDI FWS	32,350
Jarbidge Wildern.	Nevada	USDA FS	64,667
Eagle Cap Wildern.	Oregon	USDA FS	293,476
Gearhart Mountain Wildern.	Oregon	USDA FS	18,709
Hell's Canyon Wildern.	Oregon	USDA FS	108,900
Mt. Hood Wildern.	Oregon	USDA FS	14,160
Mt. Washington Wildern.	Oregon	USDA FS	48,116
Strawberry Wildern.	Oregon	USDA FS	33,003
Three Sisters Wildern.	Oregon	USDA FS	199,902
Crater Lake N.P.	Oregon	USDI NPS	160,290
Alpine Lakes Wildern.	Washington	USDA FS	303,508
Glacier Peak Wildern.	Washington	USDA FS	464,258
Goat Rocks Wildern.	Washington	USDA FS	82,680
Mt. Adams Wildern.	Washington	USDA FS	32,356
Mt. Ranier Wildern.	Washington	USDI NPS	235,239
North Cascades N.P.	Washington	USDI NPS	503,277
Pasayten Wildern.	Washington	USDA FS	505,524
Spokane Reservation	Washington	Tribal	
Bridger Wildern.	Wyoming	USDA FS	392,160
Fitzpatrick Wildern.	Wyoming	USDA FS	191,103
Grand Teton N.P.	Wyoming	USDI NPS	305,504
North Absaroka Wilder.	Wyoming	USDA FS	351,104
Teton Wildern.	Wyoming	USDA FS	557,311
Washikie Wildern.	Wyoming	USDA FS	686,584
Yellowstone N.P.	Wyoming	USDI NPS	2,020,625

APPENDIX 2

Non-attainment areas within or near the Eastside Ecosystem Management Project (from 40 CFR 81.300 revised July 1, 1994).

STATE	NONATTAINMENT AREA	POLLUTANT
California	Lake Tahoe North Shore Area (Placer County - part)	Carbon Monoxide
	Lake Tahoe South Shore Area (El Dorado County - part)	Carbon Monoxide
Idaho	Boise - Northern Ada county area	Carbon Monoxide
	Boise - Ada county	PM-10
	Shoshone county - part	PM-10
	City of Pinehurst	PM-10
	Pocatelllo area	PM-10
	Sandpoint Area - Bonner county	PM-10
Montana	Missoula county (part)	Carbon monoxide
	Flathead county (part)	PM-10
	Columbia Falls and vicinity	PM-10
	City of Whitefish and vicinity	PM-10
	Libby and vicinity	PM-10
	Ronan	PM-10
	Polson	PM-10
	Missoula and vicinity	PM-10
	Thompson Falls and vicinity	PM-10
	Helena	Sulfur dioxide
Nevada	Lake Tahoe Area	
	Carson City county (part)	Carbon monoxide
	Douglas county (part)	Carbon monoxide
	Washoe county (part)	Carbon monoxide
	Reno area	
	Washoe county (part)	Carbon monoxide
	Reno area	
	Washoe county	Ozone
	Reno planning area	PM-10
Oregon	Lakeview (urban growth boundary area)	PM-10

APPENDIX 2 (con't)

STATE	NONATTAINMENT AREA	POLLUTANT
Oregon	La Grande (area within the urban growth boundary area)	PM-10
Utah	City of Ogden	Carbon monoxide
	City of Provo	Carbon monoxide
	Salt Lake City	Carbon monoxide
	Davis county	Ozone
	Salt Lake County	Ozone
	Salt Lake county	PM-10
	Utah county	PM-10
	Salt Lake county	Sulfur dioxide
	portions of Toole county	Sulfur dioxide

32

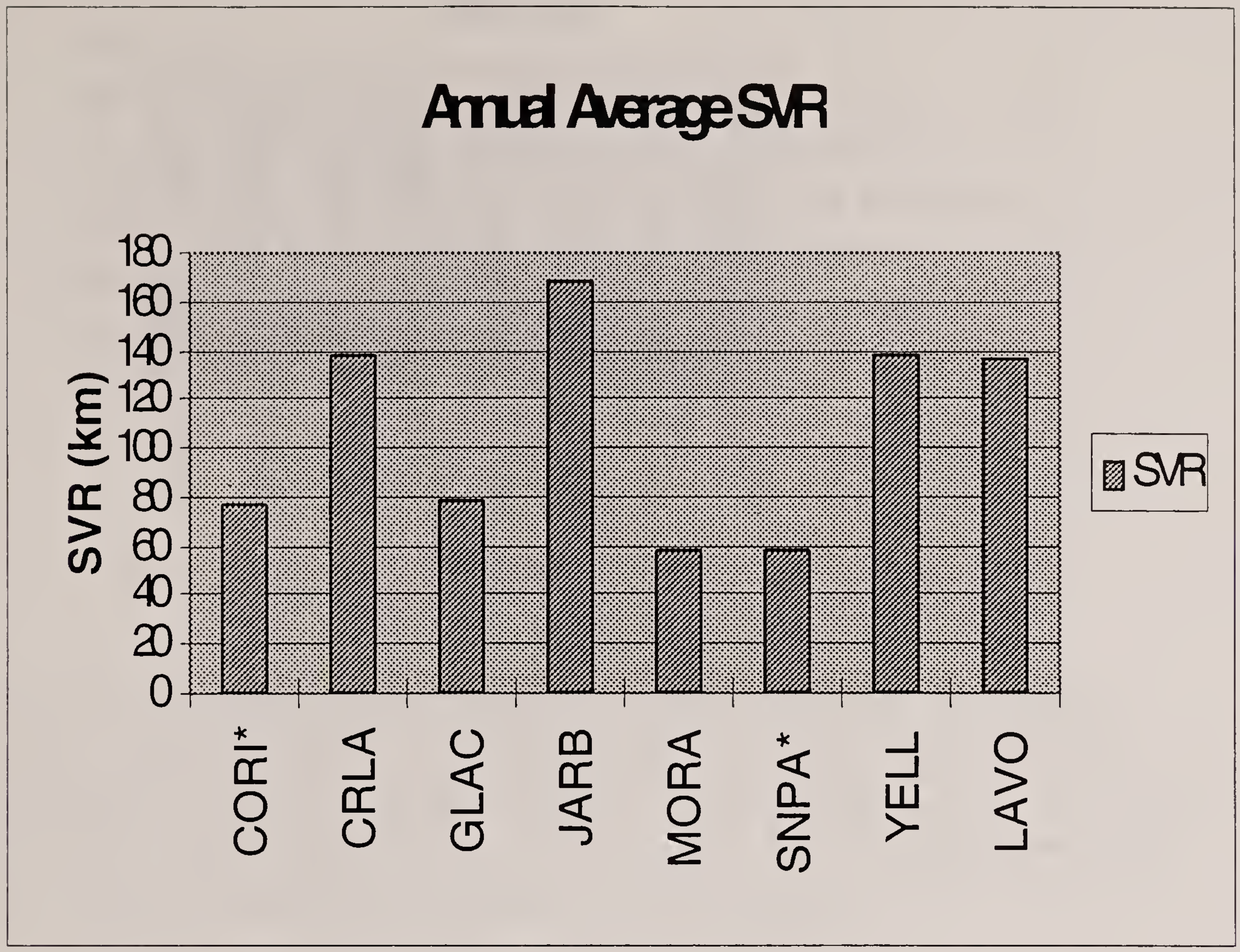

Figure 11--Standard Visual Range, expressed as an annual average, in kilometers, for the Eastside IMPROVE sites.(*The period of record for CORI and SNPA is from 6/93 to 8/94). (Columbia River Gorge Scenic Area (CORI), Snoqualmie Pass (SNPA), Crater Lake National Park (CRLA), Lassen Volcanic National Park (LAVO), Jarbidge Wilderness Area (JARB), Yellowstone National Park (YELL), and Glacier National Park (GLAC), Mount Rainier National Park (MORA)).

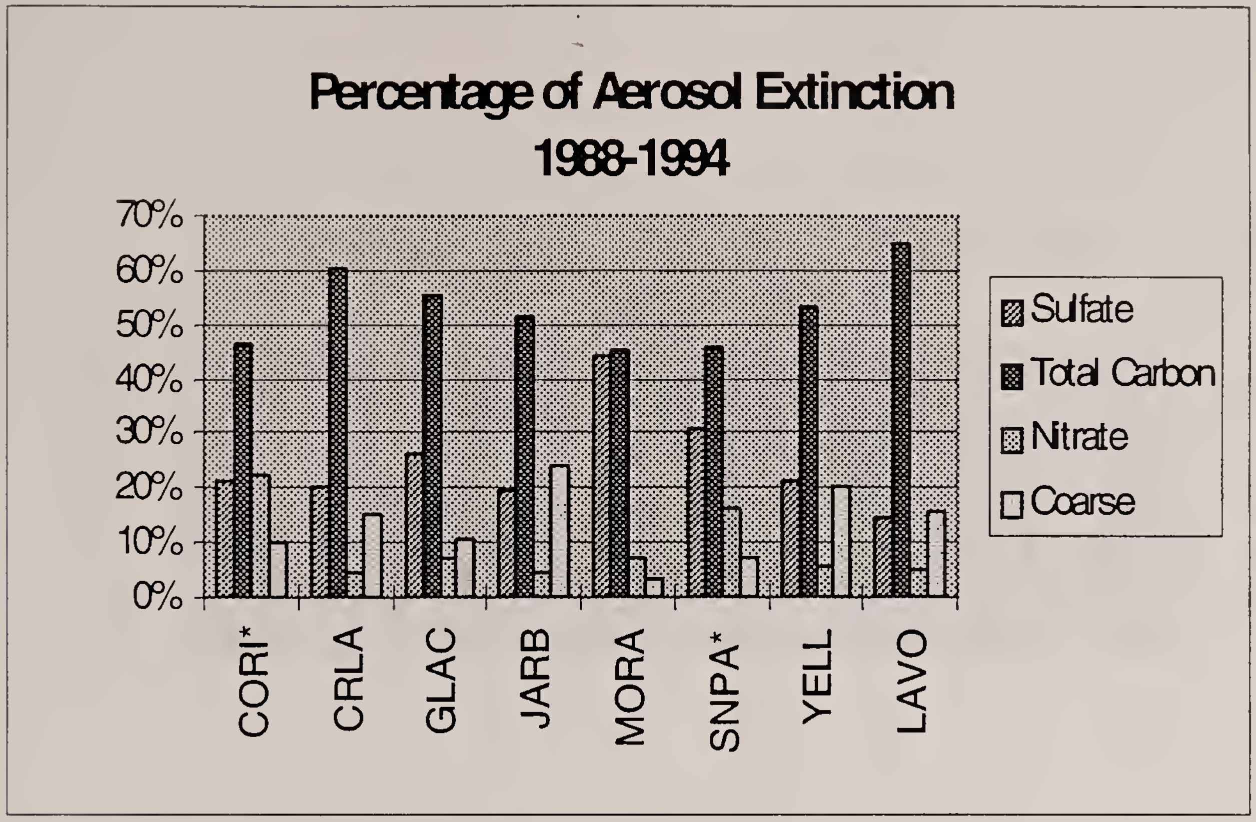

Figure 12--Aerosol extinction budget with organics and soot combined into total carbon. (*The period of record for CORI and SNPA is from 6/93 to 8/94).(Columbia River Gorge Scenic Area (CORI), Snoqualmie Pass (SNPA), Crater Lake National Park (CRLA), Lassen Volcanic National Park (LAVO), Jarbidge Wilderness Area (JARB), Yellowstone National Park (YELL), and Glacier National Park (GLAC), Mount Rainier National Park (MORA)).

34

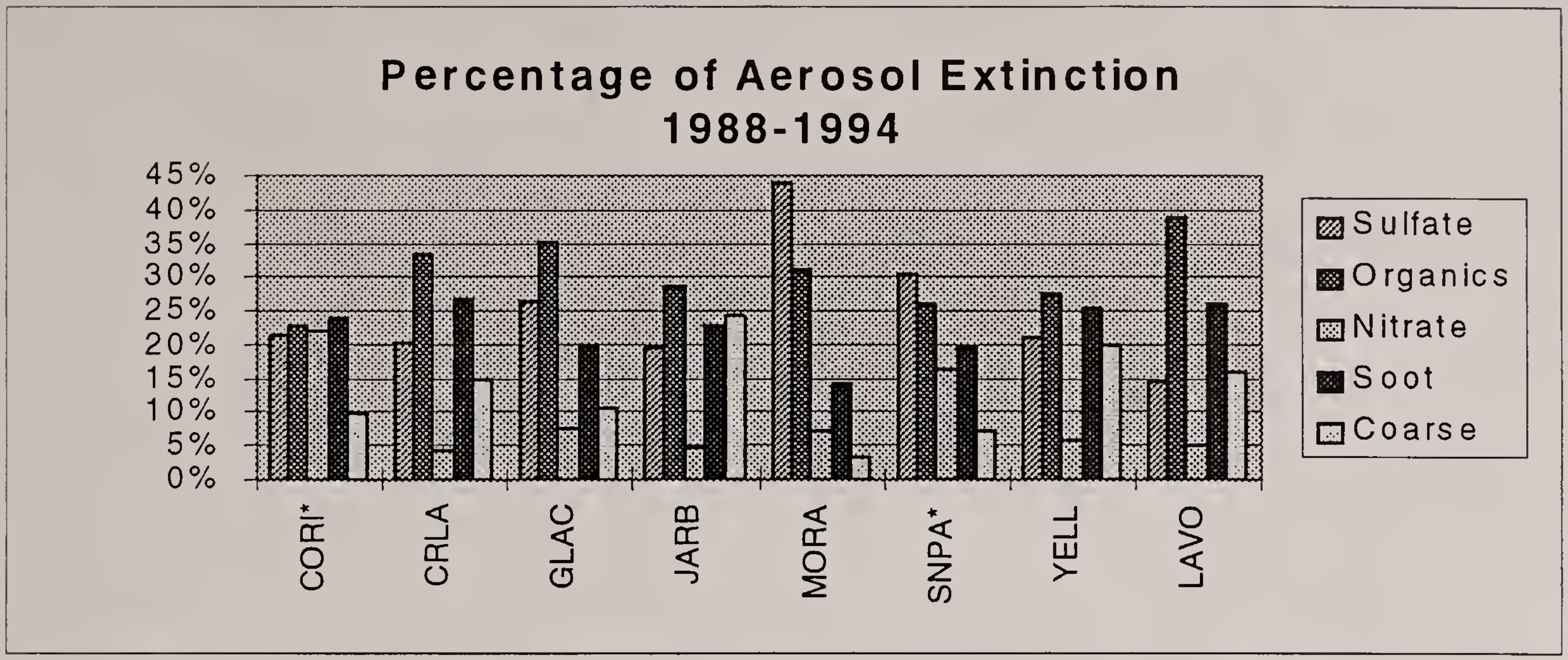

Figure 13--Percentage of light extinction due to aerosol components.(*The period of record for CORI and SNPA is from 6/93 to 8/94).(Columbia River Gorge Scenic Area (CORI), Snoqualmie Pass (SNPA), Crater Lake National Park (CRLA), Lassen Volcanic National Park (LAVO), Jarbidge Wilderness Area (JARB), Yellowstone National Park (YELL), and Glacier National Park (GLAC), Mount Rainier National Park (MORA)).